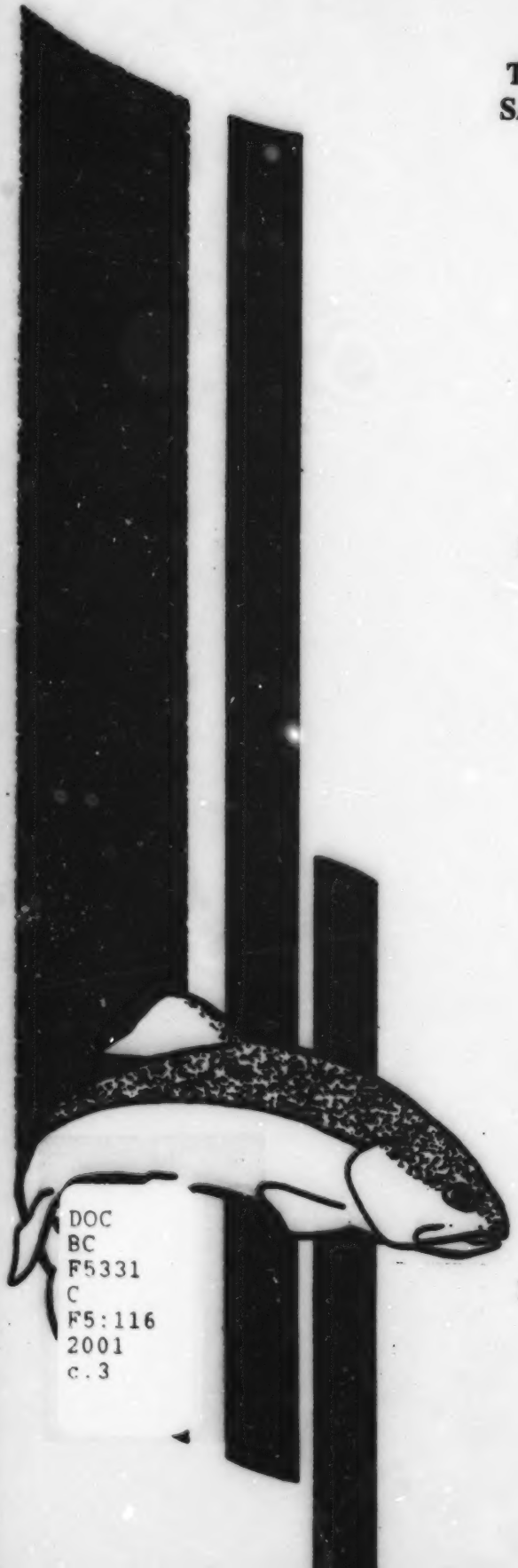

THE ROLE OF FISH CULTURE IN SALMONID CONSERVATION AND MANAGEMENT

by

Susan Pollard

Fisheries Management Branch,
Ministry of Water, Land and Air Protection
PO Box 9359, STN PROV GOV'T
Victoria, British Columbia
V8W 9M2

Fisheries Management Report No. 116
2001

BRITISH COLUMBIA

Fisheries Management Branch
Ministry of Water, Land and Air Protection
Province of British Columbia

DOC
BC
F5331
C
F5:116
2001
c.3

LEGISLATIVE LIBRARY
VICTORIA BC V8V 1X4 OCT 9 2001

National Library of Canada Cataloguing in Publication Data
Pollard, Susan Marie, 1967-
The role of fish culture in salmonid conservation and management

(Fisheries management report ; no. 116)

Includes bibliographical references: p.
Also available on the Internet.
ISBN 0-7726-4621-X

1. Salmon - Habitat - British Columbia. 2. Fish-culture - Environmental aspects - British Columbia.
3. Salmon industry - British Columbia. 4. Salmon stock management - British Columbia. I. British Columbia. Fisheries Management Branch. II. Title. III. Series: Fisheries management report (BC Fisheries) ; no. 116.

SH167.S17P64 2001 333.95'656'09711 C2001-960242-X

3 3298 00253 8099

THE ROLE OF FISH CULTURE IN SALMONID CONSERVATION AND MANAGEMENT

by

Susan Pollard

Fisheries Management Branch,
Ministry of Water, Land and Air Protection
PO Box 9359, STN PROV GOV'T
Victoria, British Columbia
V8W 9M2

Fisheries Management Report No. 116
2001

102-01625/

Abstract

Over the past 100 years, fish culture techniques have been applied extensively in salmonid management throughout the Pacific Northwest. The main purpose has been to increase production for commercial harvest and sportfishing opportunities, often as mitigation for loss of natural fish production through various land and water use activities. Ostensibly, there is the potential to increase production significantly since survival rates of juveniles while in captivity can be increased. However, more recent reviews suggest that many salmonid culture programs have not been successful in this objective and may have, in many cases, actually had a detrimental effect on already fragile wild populations of fish. It is essential that the provincial Fisheries Program ensure that its fish culture activities are consistent with conservation objectives. In addition, the risks as well as the benefits of fish culture need to be documented in a format that is accessible to various stewardship groups interested in developing local hatcheries as part of their watershed restoration activities.

The primary purpose of this document is to review the genetic and ecological risks associated with fish culture, providing examples where possible. This will help managers to identify and address these risks when considering or developing fish culture activities in the future. Secondarily, this document reviews the current provincial Fish Culture Program and provides recommendations to address conservation concerns regarding native fish species. Finally, the document concludes that fish culture is a tool to aid in fisheries management, but in the context of conservation and recovery, should be considered as experimental only until examples of successful programs can confirm its utility.

Table of Contents

Abstract i
Table of Contents ii
List of Tables iii
Introduction 1
Defining the Management Goals for Fish Culture 2
I. Rebuilding and maintaining fish populations 2
II. Enhancing fisheries 3
Weighing the Risks 4
I. Genetic risks 5
A. Random changes 5
B. Directional changes 6
C. Outbreeding and hybridization 7
II. Ecological risks 8
III. Behavioural risks 9
IV. Harvest risks 9
V. Summary 10
Potential Benefits and Opportunities Associated with Fish Culture in British Columbia 10
Review of Policies Affecting the Stocking of Provincial Fish 11
Review of Provincial Stocking Programs 11
I. Stream stocking programs 12
II. Lake stocking programs 13
Fish Culture for Conservation 14
Program options 15
A. Captive Breeding Programs – short-term/long-term 15
B. Wild broodstock/F1 releases 16
The Use of Fish Culture in a Recovery Program 17
Recovery program design 17
Incorporating an experimental approach 17
Conclusions 18
References 20

List of Tables

Table 1. Summary of all provincial policies associated with fish stocking 24
Table 2. Numbers of streams stocked in British Columbia in 1997-2000 26
Table 3. Numbers of lakes stocked in British Columbia in 1997-2000 27
Table 4. Use of non-native stocks in British Columbia streams in 1997-2000 29

Introduction

The life history strategy of salmonids lends itself well to artificial propagation. The combined traits of high fecundity (100's to 1000's of eggs per female) and high mortality (usually >90%) during first two years of life in the wild provide the opportunity for hatcheries to very quickly increase fish production by significantly improving early survival. This idea was first conceptualized centuries ago but became a panacea in the 1970's throughout the Pacific Northwest for mitigation programs where hydro dam construction and other land development devastated natural salmonid production.

In British Columbia, fish culture programs are administered by two government agencies. The federal Department of Fisheries and Oceans manages Pacific salmon and the Province manages freshwater fishes, as well as anadromous steelhead and cutthroat trout. The goal of most federal hatcheries is to enhance salmon fisheries (commercial, sport and First Nations). Provincial stocking programs are mainly directed towards creating and maintaining freshwater sport fisheries primarily in small lakes. In addition, a number of programs, particularly those for anadromous steelhead and cutthroat trout, release fish into streams, again with the goal to enhance the sport fishery but also to potentially increase natural production. In recent years, a third type of provincial program has been initiated for the sole purpose of rebuilding depleted populations – to date such activities have been restricted to steelhead and white sturgeon.

Hatchery programs are looked upon favourably by most fisheries managers, politicians and the public. The perception is that hatcheries can produce lots of fish quickly. Hatcheries are equated to jobs in the fishing industry, increased tourism and the feeling that society is providing for the fish resource. Within the past 10 years, however, several reviews have suggested that many hatchery programs, particularly for anadromous salmonids, have not lived up to expectations and may have put already fragile wild populations at even greater risk of extinction. The time has come to review the role of stocking programs in management and conservation and to ensure that all such programs supported by the province are consistent with the Fisheries Program's first objective - the *conservation of wild populations of fish and their habitat* (Fisheries Program Strategic Plan 1995-2000). In addition, consistent advice regarding stocking practices is needed to guide the ever-growing number of stewardship groups interested in rebuilding fish populations through community-run hatcheries or other forms of fish culture. It is important to understand that while fish culture has its place in fisheries management, it is not the "panacea" it was considered in the past. The intent of this paper is to provide an overview of existing literature regarding the risks and benefits of hatchery programs and to provide a basis from which to develop provincial policy and guidelines for future culture-related fisheries management.

Defining the Management Goals for Fish Culture

Defining specific management goals for a population is the first step in a species management plan, after identifying the population and its status. Kostow (1997) defined two main management goals for fisheries in general: (1) a *biological goal* to maintain or improve the status of a population to enable continued persistence and evolution indefinitely; and, (2) a *user goal* to provide or enhance various fisheries. These goals should reflect a population's status – status will determine to what extent the population can withstand pressures associated with a user goal. Two similar goals can be adopted for fish culture: (1) a *conservation goal* to rebuild or maintain a population; and, (2) an *enhancement goal* to provide or augment a fishery.

I. Rebuilding and maintaining fish populations

A conservation goal should aim to protect and restore healthy fish populations but also to protect and restore a *diversity* of healthy fish populations. Biodiversity is critical to the well-being of the natural environment and has significant implications to economics, culture and overall functioning of human society. From the biological perspective, diversity exists at three main levels: (1) genetic (variation within and among populations); (2) species (the diversity of different species); and, (3) ecosystem (the array of natural communities). Protection of genetic diversity within species provides options for that species to continue to cope and adapt under continually changing environments, particularly in the face of climate change, human impacts to habitat and exposure to new diseases. Maintaining species diversity is important to the maintenance of the complex aquatic food webs and other interactions among species and with their environment. Protecting ecosystem diversity will maintain interactions in the natural environment at a higher level.

The social and cultural impacts associated with the loss of biological diversity are fairly obvious and include reduced diversity in sportfishing and nature appreciation opportunities, as well as impacts on our spiritual associations with the environment and traditional ceremonial uses. Less apparent may be the significant economic impacts associated with reduced biodiversity. In the short term, this reduction in diversity of fish populations may not be reflected in total production in mixed fisheries situations. Over the longer term, this loss may lead to increased catch variability from year to year, increased vulnerability to disturbances, loss of future opportunities for more selective fishing (e.g. terminal techniques) and the loss of unique and desirable genetic traits, not only in wild populations but also for aquaculture development (Walters and Cahoon 1985). Once lost, biodiversity cannot be recreated naturally during a human lifespan. Such a loss will severely reduce our ability to revitalize our natural environment and maintain the quality of life that we all seek.

A recent status review in British Columbia indicated that a significant number of salmon and anadromous trout populations are considered at risk of extinction (Slaney et al. 1996). The past five years have witnessed serious declines in a number of steelhead populations, particularly on the east coast of Vancouver Island (Wightman et al. 1998), the Fraser River (Olmsted and

McGregor 1997) and Bella Coola River (Nelson et al. 1998). Rebuilding these populations through the aid of fish culture is conceptually one tool to improve status. In this case, full integration of hatchery-produced fish in natural fish production is desired with a significant, sustained increase in natural production beyond the period of hatchery supplementation. Hatchery fish should be genetically representative of the population to be rebuilt. Hatchery and wild fish function as one reproductive unit and the program would be as a temporary measure only. The potential benefits of using fish culture must outweigh the risks it poses to the natural population. One special case where this type of fish culture might be considered longer term or even indefinitely is where a permanent loss of habitat has occurred to prevent spawning or rearing. Because the population is deemed an important component of the natural community, it is artificially maintained in order to maintain balance in the ecosystem (e.g. salmon carcasses providing nutrients). Hatchery program design will depend on the specific status of a population which could vary as follows: (a) avoiding immediate extinction of a population; (b) maintaining depressed populations until factors limiting survival can be addressed; (c) re-seeding vacant habitat (re-introduction); or, (d) increasing abundance of naturally spawning populations (Allendorf and Waples 1996).

II. Enhancing fisheries

One of the top priorities of the provincial Fisheries Program once conservation concerns have been addressed is to provide and enhance sport fishing opportunities. The magnitude of freshwater sports fishing in B.C. is reflected in the sale of almost 400,000 licenses and total expenditures of almost $500 million in 1995 (BC Fisheries 1998). Provincial hatcheries play a very significant role in this economic activity. For example, in 1995 it is estimated that the provincial stocking programs supported about 49% of total angler activity by supporting fisheries through annual stocking programs on approximately 1,100 freshwater systems – primarily small lakes. Throughout B.C., a number of different types of stocking programs exist to enhance angling opportunities including:

a. providing a fishery where none previously due to inadequate spawning habitat (e.g. small lakes in the dry central interior);
b. providing specialized fishing opportunities where none previously existed (e.g. rainbow trout developed for alkaline lakes, winter lake fishing for kokanee and brook trout);
c. enhancing existing fisheries by stocking trout into systems already populated by wild trout (e.g. sterile hatchery rainbow trout stocked into systems already containing rainbow trout or cutthroat trout); and,
d. providing a harvestable catch on anadromous rivers where catch and release regulations exist for wild fish (e.g. stocking marked hatchery steelhead to allow anglers a limited harvest).

Ideally, hatchery-produced fish are physically isolated from wild fish populations so that interactions between hatchery and wild fish are minimized. Hatchery fish should not contribute to natural reproduction when the goal is to enhance fisheries.

Many hatchery programs attempt to address rebuilding and enhancement goals at once. These two goals are not necessarily mutually exclusive but will compromise one another (Allendorf and

Waples 1996). Arguably, it is more appropriate to address conservation first, and only when this objective is successful should production for a fishery be considered. A population that requires rebuilding is in a depressed state, and additional stresses should be minimized. Activities such as a low-impact catch-and-release fishery should be considered on a case by case basis.

Weighing the Risks

The management goal for a particular population will be defined by its status. The next step is to determine whether or not fish culture is an appropriate tool to address the goal – do the benefits outweigh the risks? Two key points are very significant to this discussion and should be kept in mind at all times when considering options. Firstly, the only time a hatchery "boost" to a wild population will benefit natural production is when the natural population increases rapidly in size during supplementation and the population stays large or continues to grow once a hatchery program is terminated (Waples and Do 1994). This implies that the habitat must have the capacity to cope with a significant increase in production and the reason for the decline has been or is in the process of being addressed. Any situation where the population numbers drop back down to pre-hatchery levels defeats the purpose and places serious risks on the wild population. Secondly, a recent review of salmonid conservation was unable to find a single example where temporary supplementation has been successful in increasing long-term abundance of naturally spawning populations of Pacific salmon (Allendorf and Waples 1996). In considering benefits to wild Pacific salmonids, Kostow (1997) found only one type of rebuilding program was successful - this involved re-introduction of populations to habitat that historically contained these species. No success stories for captive breeding or increasing abundance of existing populations were identified (Kostow 1997). These examples are limited to anadromous populations in the Pacific Northwest and may not capture the results of all programs. However, they suggest that any decision to use fish culture to assist with stock rebuilding initiatives must be treated as experimental until proven successful.

Perhaps one of the main reasons few if any documented success stories exist regarding rebuilding anadromous salmonid populations through fish culture is because conservation-based hatcheries are a relatively new concept (Hard et al. 1992). In addition, where fish culture has been initiated to increase production, goals have been at best vague and many programs continue indefinitely with no post-hatchery evaluation (Hilborn and Winton 1993). We are only now becoming aware of possible genetic and ecological impacts associated with stocking practices. While some impacts are inevitable, many can be avoided. The key is to minimize these impacts and then weigh the risks against the benefits - such an evaluation process has not been conducted in the past. A successful hatchery program profoundly changes the mortality profile of a population and results in higher early survival rates than in the wild (Waples 1999). However, this change will likely come with a cost.

I. Genetic risks

Evidence of highly localized adaptation in salmonid populations is becoming more prevalent in the scientific literature (Williams et al. 1997a, Taylor 1991, Wilmot and Burger 1985). Local adaptation combined with high fidelity to natal streams and relatively low straying rates results in highly structured genetic groups whose demographics, life history strategies and morphology are optimally suited to their environment. The resulting diversity within and among populations creates a large reservoir of genetic material that enables the species as a whole to continue to adapt and evolve under changing environmental conditions. Hatchery production alters the within- and among-population genetic diversity, sometimes dramatically.

Mortality from egg to smolt in the wild is extremely high. Wild fish grow under extremely strong selection pressures although random mortality (unrelated to genes) due to environmental conditions is also a significant contributor to juvenile losses. Maladapted individuals are usually removed during this period, and less fit genotypes (genetic composition of individuals) are removed from the population's gene pool. In a hatchery, survival rates improve significantly resulting in typically 50-80% egg to smolt survival. This is because natural selection pressures are relieved and environmental conditions are improved, and fish that normally wouldn't survive in the wild can survive in the hatchery environment.

A. Random changes

Collecting broodstock from fish populations is like any other type of sampling procedure – there is always a sampling error associated. Unless the entire population is removed, there will never be full representation of all phenotypes (observed morphological, life history and behavioural traits) (Allendorf and Waples 1996). Some phenotypes will be over-represented and some will be under-represented due to chance alone. These phenotypes are usually, in part, the product of different genotypes. Sampling error associated with genotype representation is called random genetic drift. This can happen in wild populations over generations, particularly those that are relatively small and reproductively isolated, or through sampling for fish culture. Over time, the effects can accumulate altering the genetic composition of the population from the original baseline population.

When hatchery-raised offspring from the sub-set of wild broodstock are released back into the wild to contribute to natural production, they can genetically "swamp" the natural population. For example, if 10 adult steelhead are removed from a population of 100, a realistic number of smolts produced from matings may be 11,250 given high survival rates (75%) in the hatchery. In the wild, the remaining 90 adults may produce 1,350 smolts (1% survival). Given estimated smolt to adult survival rates for steelhead under current conditions (1% for hatchery, 3% for wild), 113 hatchery and 41wild adults would be expected to return. The genetic over-representation by the hatchery component can significantly reduce the effective population size (*Ne*) of a population even though actual census size *N* might increase. In the above example, the ratio of returning hatchery to wild adults translates to an effective population size *Ne* (calculation based on equation in Ryman and Laikre 1991) of approximately 18, compared to 45 (expected if

all fish were left to spawn in the wild) even though the total numbers of adults returning with hatchery input is significantly larger (N=154) than without intervention (N=45). *Ne* is the actual genetic size of a population after sex ratios and relative contributions from different adults to the next generation are accounted for and is usually less than *N*. *Ne* is inversely related to inbreeding levels – the smaller *Ne* is, the greater inbreeding potential is. When relatively few adults contribute a large number of offspring for natural production, the *Ne* of the total natural population is compromised seriously, resulting in a significant loss of within-population genetic variation. The key is to find a balance between the risk of demographic extinction associated with low numbers of fish and the risk of genetic loss.

Loss of genetic variation or heterozygosity for a population can result in two problems: (1) loss of variation available for continued adaptation particularly under changing environmental conditions (e.g. ocean conditions, altered freshwater habitat); and. (2) exposure of recessive deleterious genes through increased inbreeding levels. These problems in turn reduce fitness levels of the population as a whole and in individuals, thus placing the viability of the population in jeopardy. For example, Kincaid (1976) found that a 25% loss in heterozygosity levels due to inbreeding in rainbow trout was associated with an increase in morphological deformities (38% more), decreased fry survival (19% less) and decreased weight after a year (23% less). Another study found increased levels of morphological abnormalities were associated with loss in genetic variation for a strain cultured rainbow trout (Allendorf and Leary 1988). To a large extent, these problems can be addressed through proper design of the hatchery program and knowledge of the size of the wild population.

B. Directional changes

Directional genetic changes due to selective forces in a hatchery population are more difficult to address. Whether intended or not, artificial selection and domestication of fish in a hatchery is unavoidable (Waples 1999). As soon as a fish is placed in an artificial environment, it is removed from the selective forces occurring in nature and is exposed to the selective forces of the hatchery. Traits selected for in an artificial environment are rarely desirable in a natural environment. This results in some level of reduced fitness in hatchery fish when returned to the wild. While these domestic traits might not necessarily manifest themselves under certain stable environmental conditions, they may significantly impact the population if conditions change or are unpredictable. If these fish are integrated into natural reproduction, they will reduce the fitness level of the population as a whole to some extent, at least temporarily. Two important considerations are: (1) to ensure that the reduction in fitness level is minimized via hatchery practices; and, (2) to determine if the benefits of stocking warrant the reduction in fitness (at least temporarily).

Examples of adaptive, highly selected traits include run-timing (summer versus winter, early versus late depending on hydrological regime), residency versus anadromy, fecundity, body size and shape, agonistic behaviour, homing, growth, stress and disease resistance (Hard et al. 1995). Studies have demonstrated that many of these traits have a genetic component (that is they are inherited by offspring) but may also be strongly influenced by the environment – called

phenotypic plasticity – to suite a particular set of conditions. These traits can undergo strong directional changes in hatchery conditions.

Two key periods where directional changes can occur in hatchery-raised fish, intentionally or not are:

1. Broodstock selection – For example, broodstock may be collected from the early part of the run to ensure desired numbers are reached or to provide a longer angling period (fish will return earlier and stay in the river longer before they spawn). This can result in a shift in run-timing of the total population which may not necessarily be the best option for wild production e.g. early winter-run of Stamp/Somass steelhead was preferentially selected for in the late 1980's with a corresponding run-timing shift observed in the river (Rimmer 1991). In addition, large fish may be selected to maximize numbers of eggs per female or to provide large fish for angling. In the past, broodstock goals have focussed on achieving desired numbers rather than adequately representing the phenotypic diversity of the total population.

2. Offspring rearing – Present-day hatcheries are often geared towards large-scale production under unnatural conditions that include open containers with uniform substrates and no hiding areas. Conditions encourage the selection of large, aggressive juveniles. Upon being released in the wild, the aggressive fish are more vulnerable to predation (Berejikian 1995). Very little potential to set up territories is available as juveniles are generally maintained at fairly high, often stress-producing densities. In addition, fish are conditioned by surface feeding to approach large objects on the surface and are not exposed to predation (Maynard et al. 1996a). Small fish that are not aggressive and generally don't survive as well because they can't compete for pellets.

Even where mortality is absent in the hatchery environment, domestication will occur (Waples 1999). Domestication can be reduced by minimizing the duration offspring remain in a hatchery (e.g. release as fry rather than parr or smolts) but cannot be reversed upon release in the wild even though some natural selection will occur. Relatively high post-release survival might occur under certain conditions but not under others, and the effects of domestication might only become evident at spawning or in progeny or under different environmental conditions. Byrne et al. (1992) concluded that a hatchery program, no matter how enlightened, will unlikely be able to optimize adaptive traits necessary for the long-term survival of steelhead in a natural system. The key is to minimize domestication and artificial selection as much as possible and to equalize all genotypes while in the captive environment.

C. Outbreeding and hybridization

Outbreeding and hybridization occur when individuals from different populations, or even closely related species, are interbred and offspring are produced, called hybrids. Hybridization has been a significant problem in the northwestern states, particularly where large-scale hatcheries produced a single rainbow trout strain for release in countless systems as enhancement or mitigation for hydro dam construction and permanent loss of fish habitat. Phelps et al. (1994) documented several cases where significant introgression (natural genetic characters are

swamped and lost by introduction of foreign genes) has occurred between wild rainbow trout or steelhead and cultured rainbow trout originating from different watersheds. This results in the dilution and loss of locally adaptive traits and reduction in fitness. One example of an important adaptive trait is disease resistance. This trait has a genetic component and can vary significantly among populations, for example in rainbow trout (Currens et al. 1997) and Atlantic salmon (Hindar et al. 1991), depending on their history of exposure to different diseases.

Hybridization has also occurred extensively between native cutthroat trout and introduced rainbow trout in some northwest states (Hawkins 1997, Busack and Gall 1981, Dowling and Childs 1992). Campton and Utter (1985) and Hawkins (1997) observed that natural hybridization between coastal cutthroat trout and steelhead occurs to some extent with hybrids existing in one section of a stream, and pure populations of each species persisting in upper and lower sections. However, where cutthroat trout populations have evolved in isolation of other species (particularly interior systems where no reproductive barriers have evolved), stocking rainbow trout creates a high risk of hybridization, introgression and the loss of pure cutthroat populations (reviewed in Benke 1992).

Hybridization between native and non-native species is prevalent in the States and may occur in B.C. For example, the non-native brook trout (*Salvelinus fontinalis*) has been stocked extensively into native bull trout (*S. confluentus*) systems throughout the Pacific Northwest. Because brook trout mature at an earlier age than bull trout and have less stringent habitat requirements, they can have a serious impact on bull trout populations through competition and introgression. Hybrids have been documented in several jurisdictions including Alberta, Montana and Oregon (reviewed in Markle 1992).

II. Ecological risks

A major ecological consideration is the finite carrying capacity or the ability of a particular habitat to support fish. This issue exists both in freshwater and in marine environments, but only recently has ocean survival due to marine carrying capacity been considered a factor. When the carrying capacity of a system is surpassed through over-stocking with cultured fish, competition with the native resident fish and juvenile salmonids increases significantly (examples in Viola and Schuck 1995, McMichael et al. 1997). When a system continues to receive a constant input of hatchery juveniles, natural production may be forced to decrease, particularly when carrying capacity is approached or surpassed. Kostow (1997) concluded that if natural production is stable or declining, maintaining a constant high input of hatchery fish will result in a replacement value for the natural population that is less than one. This effect will accumulate over time and, rather than enhancing a population's abundance, hatchery production may simply replace natural production, and the system becomes increasingly dependent on continued hatchery input to maintain numbers. This problem is exacerbated if the fitness of hatchery fish is less than that of wild fish. Unfortunately, in many situations where habitats are perturbed and the carrying capacity is reduced, hatcheries have been used to try to increase numbers with serious consequences to remnant wild populations.

The return rate of hatchery-raised adults (even progeny of locally collected wild broodstock) is often lower than that of wild adults (reviewed in Hindar et al. 1991; Busack and Currens 1995; Maynard et al; 1996, Labelle et al. 1997) although the reason for this may be one of several including genetic, behavioural or imprinting problems. For example, reduced survival has been observed in hatchery-raised steelhead from the Keogh River. During high ocean survival period (mid-late 1980's), wild smolt-adult return rates averaged 18%, whereas first-generation hatchery fish averaged 7% (Ward et al. 1994). This is a significant difference and suggests that in order to approach wild returning numbers, over 2.5 times the number of hatchery smolts would be required. Increasing production numbers is a fairly simple exercise for culture facilities but may be an issue where habitat and resources are already limited.

Systems that have received hatchery fish to increase total production often experience the opposite effect, that is a reduction in natural production over time. McMichael et al. (1997) observed significantly reduced growth in wild resident rainbow trout associated with the stocking of hatchery steelhead smolts that residualized (didn't migrate). Nickelson et al. (1986) compared a number of Oregon coho streams that did and didn't undergo stocking for rebuilding purposes. The majority of systems that were stocked had lower natural productivity levels at the end of the study.

III. Behavioural risks

Learned behaviour during early life history stages contributes significantly to survival. Cultured salmonids demonstrate little concealment behaviour, weak territoriality, and strong aggression once released into the wild (reviewed in Hindar et al. 1991; and Maynard et al. 1995, 1996). Maladaptive aggressive behaviour results in a greater expenditure of energy and puts these individuals at greater risk of predation (Maynard et al. 1995). Inept foraging behaviour and habitat utilization have also been observed in hatchery fish upon release into the natural environment (Maynard et al. 1995, 1996; Hesthagen et al. 1995). Learned behaviours not only affect the survival of hatchery-raised fish, but may also impact wild populations through increased inter- and intra-specific interactions.

IV. Harvest risks

Hatchery production can create a serious mixed-stock fisheries problem because hatchery productivity is higher than the natural productivity of many systems. When harvest levels are geared to hatchery-produced fish, over-exploitation of some wild populations is probably inevitable. This is evident in stocks of commercially fished salmonids that are artificially enhanced. Walters and Cahoon (1985) suggested that rebuilding and enhancement efforts might be one reason for the decreasing spatial diversity of salmon stocks in B.C. While some large, enhanced systems may see increased returns to spawning grounds, many smaller stocks have disappeared and even some larger stocks have declined significantly since 1950 (Walters and Cahoon 1985). In Washington, the loss of wild coho runs in the lower Columbia River has been attributed to high-seas and in-river commercial fishing geared to take advantage of the large

returns of hatchery-produced coho; an estimated 85-95% of the run was harvested as a result (Committee on Protection and Management of Pacific Northwest Anadromous Salmonids 1996). The Province stocks only non-commercial salmonid species and likely does not experience mixed-stock problems. However, the availability of harvestable hatchery fish may increase fishing pressure on wild fish populations by anglers in some systems.

V. Summary

The above description of risks associated with fish culture is not meant to suggest that all hatchery efforts are harmful. The purpose of this review is to ensure that the reader is aware of some hatchery-related problems that must be addressed when considering or designing a hatchery program. Many of the examples referenced are those associated with poor practices conducted in the past and the use of hatcheries to address the symptoms not the problems. That so many risks do exist indicates that we must be cautious in future applications of fish culture.

Potential Benefits and Opportunities Associated with Fish Culture in British Columbia

The Provincial Fish Culture Program provides significant social and recreational benefits to the residents of British Columbia, with considerable economic spin-offs. For example, 70% of freshwater angling effort occurs on stocked lakes in the Cariboo, Okanagan and Thompson Nicola regions, generating major economic benefits to these regions (Brian Chan, provincial Fisheries Program, Kamloops, per. comm.). Some of the most popular and productive fisheries in the province are fisheries supported by annual stocking programs (e.g. Sheridan, Dragon, Stump, Tunkwa, Paul, Roche, Beaver, Premier and Whitetail Lakes) (D. Peterson, provincial Fisheries Program, Victoria, per. comm.). Stocking programs cost the province about $7M annually but direct expenditures by anglers are estimated at $200M per year (D. Peterson, per. comm.). Many stocked systems are easily accessible by families and provide fishing and fish viewing experiences where none would otherwise exist, particularly in urban areas. Some specific stocking programs in the province combine the use of specialized stocks with catch and gear restrictions (e.g. winter fisheries, trophy fisheries) to enhance the fishing experience year round. For example, sterile rainbow trout are stocked to improve fish quality in highly productive lakes that have no spawning habitat. Sterility prevents early maturation at a small size and females from becoming "egg bound" (and therefore disinterested in bait/lures). In addition, only sterile brook trout strain are now stocked in B.C. to provide sport fisheries and to avoid possible hybridization with native char.

Stocking efforts may also aid in the protection of some vulnerable wild fish populations by shifting the fishing pressure to stocked systems. The Stamp/Somass and Chilliwack steelhead programs are examples where stocking with hatchery fish has provided extremely popular recreational fisheries with an allowable harvest, while possibly reducing effort on smaller wild-only systems nearby.

Finally, fish culture for conservation, particularly to rebuild depressed populations and preserve remnant populations, has great potential. As the number of populations considered threatened, endangered or non-viable increases, we may have to turn more to captive rearing as a tool to aid in recovery programs, particularly where other less invasive strategies (i.e. regulations, habitat protection) have failed.

Review of Policies Affecting the Stocking of Provincial Fish

A summary of existing provincial policies that are relevant to the use of fish culture is presented in Table 1. Some of these policies require updating to incorporate the concept of fish culture for conservation, the use of captive breeding, program life spans, monitoring and evaluation, and to ensure that impacts on native, wild populations are minimized. At present, the goals, program design and rationale are usually proposed by regional offices requesting stocked fish, making standardization difficult although these requests must be reviewed by the provincial Fish Culture Program and the Transplant Committee.

Increasingly, fisheries management agencies are being held responsible for the decisions that impact aquatic ecosystems. A standard provincial approach to the use of fish culture to provide guidance to provincial fisheries management is needed. This does not mean that every decision can be based on absolute certainty regarding success or impacts. As indicated, fish culture for recovery is a relatively new concept. There will be various options available for any given situation and decisions will be partially based on limited budget and regional priorities. However, the development of guiding principles on the appropriate use of fish culture, as well as more detailed protocols and guidelines that can be established for the entire province would provide a more defensible approach to hatchery-related fisheries management.

Review of Provincial Stocking Programs

The Provincial Fish Culture Program is often considered to be one of the more conservative hatchery models in existence in western North America. About 85% of provincial programs are designed to provide fisheries where none previously existed. Most steelhead trout programs use only locally-derived progeny, and broodstock are usually of wild origin (although they may be wild-spawned progeny of hatchery-raised fish). However, there is a need to update some programs and standardize procedures, particularly as more fish populations continue to decline and conservation-based hatcheries to support recovery programs are deemed necessary.

A fairly qualitative assessment of the past 4 years of provincial stocking (Table 2 and 3) indicates that the various risks associated with hatchery use probably vary significantly with the regions. The lake component which makes up over 90% of the stocking program is difficult to evaluate without obtaining regional inventory records that describe fish barriers above and below stocked systems, and the presence of native fish populations and other species prior to stocking and presently. This is beyond the scope of this paper. Also, many of the small lakes stocking

programs have been in place continuously for decades – it is now impossible to evaluate the pre-stocking situation.

Given the variability in current programs throughout the province, one of the first steps should be to develop a standard management plan for every stream that receives hatchery fish. This should also be considered for those lakes that are open (i.e. no barriers at inlets and outlets) in fish-bearing watersheds. These plans should include a background on native fish species presence, potential risks associated with stocking, stock(s) to be used, lifespan, goals (program, release and returns), and benchmarks for evaluation. The risks and recommendations specific to the two types of stocked systems, streams and lakes, are outlined in the following sections.

I. Stream stocking programs

Stream stocking is a much riskier undertaking than lake stocking if we assume the majority of stocked lakes are closed. The potential for dispersal and wide-spread interaction with native wild fishes is high in streams. This type of stocking has been highly detrimental to natural fish production for many coastal Washington and Oregon streams. In 1974, Montana recognized the risks associated with stream-stocking and established a wild fish policy that stopped the stocking of hatchery fish in streams capable of producing self-sustaining trout populations (Yuskavitch 1999).

The Province has consciously limited stream-stocking programs, particularly in the past few years (Table 2). Stream stocking now makes up less than 5% of all provincial culture programs. Even over the past 4 years, stream stocking has been reduced by almost 50%. Several of the programs that release rainbow trout into streams are converting to 100% non-reproductive.

With regard to B.C.'s current stocking programs, the greatest genetic risks to native populations occur where non-local[1], reproductively capable trout stocks. Specifically, this applies to cutthroat trout (especially anadromous) and to a lesser extent, rainbow trout, bull trout and kokanee (Table 4). In these cases, there is a high risk of outbreeding and genetic homogenization of native populations. Non-local anadromous cutthroat trout were stocked into 22 locations in the lower Fraser in 1997 and 1998 (combined) although this number dropped considerably in 1999 and 2000 to 8 locations (Table 4). Similarly, a couple of Vancouver Island streams were stocked with anadromous cutthroat trout strains originating from other systems. In all of these cases, the goal of these programs has been to enhance the sports fishery. However, there has been little evaluation to determine if these efforts have actually achieved this goal or if there has been an impact to the native populations. Release goals are fairly arbitrary (not based on carrying capacity or available habitat in many cases) and programs have no defined life span so usually continue indefinitely. Hybridization between cultured and wild cutthroat trout is likely occurring at some level and may seriously impact the unusually localized genetic population structure observed for this species (Williams et al. 1997b, Johnson et al. 1999).

[1] For the purposes of this review, "non-local" refers to any stock of fish that doesn't originate from the stream or lake into which it is being stocked.

Genetic risks associated with the loss of diversity and domestication are an issue for stocking programs using local steelhead or cutthroat trout sources. Vancouver Island and Lower Mainland regions annually release steelhead juveniles into anadromous streams. All programs on Vancouver Island use local broodstock, as do lower Mainland programs with the exception of two (Big Silver and Stave) where native populations either never occurred or were extirpated earlier this century. With the exceptions of the Coquihalla program and the recently initiated Living Gene Bank program for east coast Vancouver Island populations, the goal of anadromous steelhead programs has been mainly to enhance the fishery, with an undefined secondary goal of increasing natural production or at least reducing the fishing pressure on wild steelhead. Unfortunately, none of these programs have been evaluated adequately in terms of success or the impact to wild steelhead populations. Again, there are no benchmarks associated with most of these programs. Release goals tend to have some biological foundation, based on available habitat or carrying capacity, but are not evaluated rigorously. Release goals are reduced somewhat arbitrarily if observed hatchery to wild ratios in returning adults are considered too high (>50%) or broodstock is difficult to obtain. However, there are no standards or policies in place to support changes.

Ecological risks exist for stream stocking programs regardless of whether hatchery fish are sterile or not. Effort should be made to ensure programs are consistent with conservation goals from a genetic and ecological perspective.

The following is a list of recommended actions that should be taken to address conservation concerns:

- Review and develop management plans for stocking programs involving non-local fish releases to determine if these streams and rivers should be maintained as hatchery systems or reclassified as wild fish only. This review should evaluate impacts and benefits including those to the sports fishery. Table 2 summarizes all of these stocking programs.
- Similarly, review and develop management plans for all stocking programs involving the releases of locally-derived reproductive fish into streams. This includes anadromous cutthroat trout, steelhead and bull trout stocking programs occurring in Region 1, 2, 4W and 6.
- For programs (particularly steelhead in Region 1 and 2) with a rebuilding goal, a standard methodology must be developed to determine when to initiate or terminate such a program, and how to conduct the program. Programs should be considered experimental due to the lack of evidence that such programs work for anadromous salmonids. Given this recommendation, a new policy to describe the use of fish culture for conservation is necessary.

II. Lake stocking programs

As indicated, lake stocking programs are presently more difficult to evaluate in terms of potential risks because of the additional information required including existence of upstream/downstream barriers to fish passage and presence of native fish species. British Columbia has an extensive brook trout stocking program that releases fish into lakes of all regions except the lower

Mainland and Vancouver Island (123 lakes in 2000)(Table 4). Some brook trout stocking programs have been in place for 40 years and, and many systems receiving brook trout were open to waters that contain bull trout, a provincially blue-listed species. To address the hybridization issue, the Provincial Fish Culture Section has committed to stocking only 100% non-reproductive brook trout (only jurisdiction in North American currently doing so). In addition, the provincial Fisheries Program has implemented a policy of only stocking brook trout into previously stocked and assumed closed systems. In addition, stocking into streams and rivers was terminated in 1990. The Fish Culture Section has initiated several brook trout replacement stocking trials utilizing sterile domestic rainbow trout. However, brook trout continue to be observed in streams of several regions containing native bull trout populations (e.g. personal observation in Kinuseo River, and Skagit River (McPhail and Baxter, 1996)), and there is still a risk of ecological interactions with native fishes.

Cultured rainbow trout based on mainly 4 strains (Pennask R., Blackwater R., Tzenzicut L. and Fraser Valley domestic) are released into lakes throughout all regions of B.C. With renewed interest in the freshwater sport fishing industry, the numbers of lakes stocked has actually increased slightly in the past 4 years (Table 3). However, the number of systems stocked with sterile fish is increasing. While 40% of these systems received sterilized fish in 2000, there is still the potential for genetic and ecological interactions with native cutthroat trout and rainbow trout in some lakes and rivers.

The following is a list of recommended actions to ensure that provincial lake stocking programs are consistent with conservation objectives:

- Stocking programs for lakes that are considered open and/or contain native wild species of fish should be re-evaluated based on the presence of native fishes, existence of inlet/outlet barriers, species stocked, goals of program, and associated risks. (This is already partially covered by existing stocking policy but information needs to be compiled in a central database).
- Similar to brook trout, the stocking of non-native rainbow trout strains should only occur in completely closed systems where native rainbow or cutthroat trout do not occur.

Fish Culture for Conservation

Fish culture for conservation purposes (i.e. rebuilding a native population) must be considered experimental (an unproven tool) and managed adaptively (be prepared to adapt strategy as more information becomes available). Such a program should only be considered in the following situations:

1. Extreme depression or decline - The population faces possible demographic/genetic extinction because of consistently low numbers over at least one generation, or continuous significant decline where natural recovery is unlikely in short-term. Other less invasive conservation measures such as restrictive regulations have not improved status.

2. Chronic depression - The population is believed to be stuck in a "pit of low numbers" because of some sort of depensation mechanism and could use a temporary boost. In this case, the problem for decline has been/is being addressed.

A population that is currently depressed but has a good likelihood of recovery relatively quickly (within two generations) because the problem(s) for decline has been alleviated should not be considered as a candidate for conservation fish culture.

Program options

A. Captive Breeding Programs – short-term/long-term

Captive breeding programs involve rearing fish in captivity for at least an entire life cycle and have the potential to produce large numbers of fish in a single generation (Hard et al. 1992). Captive breeding programs for the re-introduction of various species including several salmonids and sturgeon have been used fairly extensively in Europe (Philipparte 1995). Generally, it is considered a "last-resort" effort to preserve a remnant population when all other options have been exhausted (Philipparte 1995, Schiewe et al. 1997). Most fisheries geneticists recommend its use only as a temporary measure. Short-term captive breeding programs to rescue populations from extinction have been successful for some resident fish species in Europe and New Mexico (Philipparte 1995). However, this technique must be treated as experimental for Pacific salmonids where programs are too young and too few to evaluate success to date (e.g. Snake River sockeye, Dungeoness chinook, Rogue River coho; T. Flagg, National Marine Fisheries Service, Washington, per. comm., R. Waples, National Marine Fisheries Service, Washington, per. comm., K. Kostow, Oregon Dept. of Fish and Game, Oregon, per. comm.).

There are several life-history stages at which to establish a living gene bank or captive founder population (Philipparte 1995):

1. Mature / spawning fish – this stage can be released back into the wild after spawning, but likely will not contribute that year to production and could impact wild reproduction; also, large numbers for breeding that are adequate to address genetic requirements are difficult to obtain.
2. Eggs, fry, parr – these stages quickly adapt to a captive environment, reducing stress of handling but also likely to undergo significant domestication and artificial selection; large numbers may be relatively easy to obtain but a random sample difficult to ensure. Collecting fish at the fry or parr stage might be a problem where sympatric populations of steelhead and rainbow trout exist. The captive breeding program for Dungeoness River chinook relies on sub-sampled eggs from natural redds in the river.
3. Smolts – this stage has experienced more natural selection than earlier stages but may have greater difficulty adapting to the captive environment. Where sympatric populations of resident rainbow and steelhead trout exist, this is the preferable stage to collect for steelhead. The Vancouver Island Living Gene Bank program was established using mainly smolts as

founders (75% survival after one year was observed in the Vancouver Island Living Gene Bank – Ray Billings, Hatchery Manager, per. comm.).

4. Sub-adults – this stage may be more readily available than mature fish (depending on species) but will likely have a reduced capability to mature properly. This stage has +not commonly been used (not applicable to anadromous stocks).

The lifespan of a program might be short-term or long-term depending on the situation. A short-term program, one generation preferably, would be appropriate in situations where a population is severely depressed but some natural production can still occur. The main objective would be to provide a temporary "boost" to the natural population. A long-term (greater than two generations) program might be the only way to preserve a population where there is little or no natural production due to lack of habitat and no chance for improvement in the near future.

Release depends on the goals of the program. Progeny (F_1) of captively-reared wild spawned individuals are released in a short-term program to minimize generations in captivity. In the case of a long-term program, F_x progeny may be released after several generations of captive breeding if conditions improve such that natural reproduction might occur once more. Time of release may occur at various life-history stages as listed below. However, research is needed to determine the best strategy – this will vary depending on system and species involved.

1. Mature/spawning fish – This allows for the most natural re-introduction, including natural mate selection and wild-spawned offspring. The risk in this type of program is that captively raised spawners may be behaviourally maladapted to undergo the natural spawning process, or too few are released to positively affect natural production. Also these fish may disrupt wild fish spawning. However, an experimental program for Rogue River coho releasing 300 pre-spawning adults/year appears to be successful to date in terms of producing progeny (K. Kostow, per. comm.).
2. Eggs/fry/smolts – The younger the life history stage, the less domestication individuals will have experienced but the greater the mortality rate upon release. If smolts are released, timing and location are key considerations to avoid residualization.

B. Wild broodstock/F_1 releases

This is the most common practice currently in use in B.C. for provincial steelhead programs distinguishing them from other agencies' programs that often rely on "recycled" hatchery fish (F_2 or more) or captively maintained broodstock. The use of wild broodstock minimizes the number of generations exposed to domestication and has the greatest likelihood of retaining original characteristics of the population. Use of wild broodstock requires a reasonable number of returning adults to the system to (1) meet genetic requirements for fish culture, (2) minimize impacts to remaining wild broodstock in the system through competition, and (3) avoid compromising overall genetic variation when re-introduced to the wild population.

The F_1 offspring can be released at various stages:

(1) Eggs – This stage reduces exposure to the artificial environment, and the main risks are the absence of mate selection and the brief period in the hatchery before eggs are planted. However, it also reduces the benefits of using fish culture, namely increasing survival. It is most appropriate where freshwater habitat is healthy but vacant.

(2) Fry – This is one of the most popular life history stages at which to release salmonids, particularly where vacant fry habitat has been identified. Again, release at this stage minimizes domestication effects, and likely improves the imprinting process. It is also an appropriate stage to release where there is vacant habitat. However, survival is also reduced significantly compared to smolt releases and may defeat the purpose of fish culture – this has often been the experience of Provincial stocking efforts. In practical terms, marking is difficult at this stage.
(3) Parr – This is not a common life history stage to release. Chance of residualization is fairly high for parr or pre-smolts released at inappropriate time or size.
(4) Smolts – This life history stage is used in most provincial steelhead programs currently. This stage maximizes juvenile survival rate and avoids freshwater habitat issues. Residualization can occur but is minimized by appropriate timing, location and size at release. Marking is easiest at this stage. However, domestication is highest for this life history stage, and imprinting might be reduced resulting in increased rates of straying.

The Use of Fish Culture in a Recovery Program

Recovery program design

Incorporating fish culture into a recovery program as an appropriate tool to help rebuild a population depends on a number of factors. These factors include population status and productivity, risks to the wild population, the reason(s) for decline, actions to address problems taken already, and costs. Information identifying status will come from regional assessments and the provincial standards for steelhead conservation levels (described in Johnston et al. 2000). No single answer exists for most situations as there are many uncertainties, and a variety of options exist. Each situation must be evaluated separately but a standard decision-making process can still be followed. Provincial policy to guide decision-making must be developed to ensure that the various risks are addressed and progress can be evaluated.

Incorporating an experimental approach

Given the uncertainties associated with fish culture for conservation, it is important to adopt an experimental approach to test various prescriptions in different situations. Budgetary constraints will limit the extent of testing but within these bounds there are some key questions to be addressed at least in the short term. These questions include:
(1) What are relative contributions of hatchery versus wild broodstock to the next generation – particularly, hatchery fish derived from different rearing technologies?
(2) What are the relative survival rates of hatchery juveniles raised under different conditions versus wild fish?
(3) What is the impact of hatchery raised fish on a wild population? On natural productivity?

East Coast Vancouver Island steelhead status is considered to be at an all-time low, and recovery efforts including the Living Gene Bank program are underway currently. While this is not a good situation, it provides the opportunity to test various options including:

(1) no hatchery treatment
(2) F_1 only releases from wild broodstock
(3) F_1 Living Gene Bank (LGB) raised progeny

There are always risks associated with a "learning by doing", "experimental management" approach (Walters 1997). On the other hand, this is probably the only way to truly test the options under real conditions. Originally, seven populations of east coast Vancouver Island steelhead were placed in the Living Gene Bank (LGB). Five of these populations are considered at high risk and two are considered at moderate risk (Wightman et al. 1998 – Draft Recovery Plan for East Coast Vancouver Island Steelhead). Some consideration of status and logistics resulted in removal of 4 of these populations. Once the status of these and the other populations of concern in the recovery plan have been evaluated according to provincial standards (based on Johnston et al. 2000), appropriate management options should be defined for each population. Recovery plans are the most extreme of management options and should be developed only for the populations assigned the most "at risk" status level. It is only within recovery plans that captive breeding should be considered as one tool.

Not all LGB broodstocks should necessarily be used immediately. The decision to use LGB progeny for release will depend on:

- continued status of population
- risk to nearby population(s)
- reason(s) for current status
- evaluation potential
- status of LGB broodstock and progeny
- financial resources

The use LGB fish may be a viable rebuilding option, but is an unproven one and requires an adaptive management plan. Implementing LGB releases must be based on sound rationale and an experimental design that allows for proper evaluation of the program. The program can be terminated prematurely or altered if serious problems occur, status changes or more information is obtained. Initially, specific streams considered in the most serious threat of extinction should be selected for different treatments (including LGB option) depending on evaluation capabilities for the system. Evaluations including wild stock status, LGB stock status, release results, effects on wild population, return rates and post-program stock status must be conducted yearly.

Conclusions

Several conclusions can be made from this review. Hatcheries can provide substantial economical and social benefits by providing and enhancing freshwater sport fishing opportunities. However, fish culture has many associated risks that can severely impact native, wild fish populations. Past experience has made us more aware of many problems and ways to

avoid or at least minimize them in the future. These issues must be addressed provincially. Several existing provincial policies regarding fish culture are out-dated or vague and require alterations and detailed protocols. In addition, a review of specific stocking programs associated with non-native species and stocks, as well as stream-stocking, must be conducted to ensure that the Fish Culture Program is compatible with conservation goals. Finally, conservation fish culture is a relatively new concept with no existing provincial policy - it is not a proven tool and must be treated on an experimental basis.

References

Allendorf, F.W., and Leary, R.F. 1988. Conservation and distribution of genetic variation in a polytypic species, the cuttrhoat trout. Cons. Biol. 2:170-184.

Allendorf, F.W., and Waples, R.S. 1996. Conservation and genetics of salmonid fishes. *In* Conservation genetics – case histories from nature. *Edited by* J.C. Avise and J.L. Hamrick. Chapman and Hall, New York.

Behnke, R.J. 1992. Native trout of western North America. American Fisheries Society, Bethesda, Maryland.

Berejikian, B.A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (*Oncorhynchus mykiss*) to avoid a benthic predator. Can. J. Fish. Aquat. Sci. 52:2476-2482.

BC Fisheries. 1998. Fresh water sport fishing in British Columbia: Results of the 1995 National Survey of Sports Anglers. Draft. Policy and legislation Branch, BC Fisheries.

Busack, C.A., and Currens, K.P. 1995. Genetic risks and hazards in hatchery operations: fundamental concepts and issues. *In* Uses and effects of cultured fishes in aquatic ecosystems. *Edited* by H.L. Schramm, Jr. and R.G. Piper. American Fisheries Society, Bethesda, Maryland.

Byrne, A., Bjornn, T.C., and McIntyre, J.D. 1992. Modeling the response of native steelhead to hatchery supplementation programs in an Idaho river. North Am. J. Fish. Mngt. 12:62-78.

Campton, D.E., and Utter, F.M. 1985. Natural hybridization between steelhead trout (*Salmo gairdneri*) and coastal cutthroat trout (*Salmo clarki clarki*) in two Puget Sound streams. Can. J. Fish. Aquat. Sci. 42:110-119.

Committee on Protection and Management of Pacific Northwest Anadromous Salmonids. 1996. Chapter 12. *In* Upstream. National Academy Press, Washington, D.C.

Currens, K.P., Hemmingsen, A.R., French, R.A., Buchanan, D.V., Schreck, C.B., and Li, H.W. 1997. Introgression and susceptibility to disease in a wild population of rainbow trout. North Am. J. Fish. Mngt. 17:1065-1078.

Dowling, T.E., and Childs, M.R. 1992. Impact of hybridization on a threatened trout of the southwestern United States. Cons. Biol. 6:355-364.

Hard, J.J. 1992. Genetic monitoring of life-history characters in salmon supplementation: problems and opportunities. *In* Uses and effects of cultured fishes in aquatic ecosystems. *Edited* by H.L. Schramm, Jr. and R.G. Piper. American Fisheries Society, Bethesda, Maryland.

Hard, J.J., Jones, Jr., R.P., Delarm, M.R., and Waples, R.S. 1992. Pacific salmon and artificial propagation under the Endangered Species Act. NOAA Technical Memorandum NMFS-NWFSC-2.

Hawkins, D.K. 1997. Hybridization between coastal cutthroat trout (*Oncorhynchus clarki clarki*) and steelhead (*O. mykiss*). PhD. dissertation. University of Washington.

Hesthagen, T., Hegge, O., Skurdal, J., and Dervo, B.K. 1995. Differences in habitat utilization among native, native stocked, and non-native stocked brown trout (*Salmo trutta*) in a hydroelectric reservoir. Can. J. Fish. Sci. 52:2159-2167.

Hilborn, R., and Winton, J. 1993. Learning to enhance salmon production: lessons from the salmonid enhancement program. Can. J. Fish. Aquat. Sci. 50:2043-2056.

Hindar, K., Ryman, N., and Utter, F. 1991. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. 48:945-957.

Johnson, O.W., Ruckelshaus, M.H., Grant, W.S., Waknitz, F.W., Garrett, A.M., Bryant, G.J., Neely, K., and Hard, J.J. 1999. Status review of coastal cutthroat trout from Washington, Oregon and California. NOAA Technical Memorandum NMFS-NWFSC-37.

Johnston, N.T., Parkinson, E.A., Tautz, A.F., and Ward, B.R. 2000. Biological reference points for the conservation and management of steelhead, *Oncorhynchus mykiss*. Canadian Stock Assessment Secretariat, Research Document 2000/126.

Kincaid, H.L. 1976. Inbreeding depression in rainbow trout. Trans. Am. Fish. Soc. 105:273-280.

Kostow, K. 1997. A framework for evaluating the risks and benefits of hatchery programs and developing program designs. DRAFT report developed for the National Marine Fisheries Service and Oregon Department of Fish and Wildlife.

Labelle, M., Walters, C.J., and Riddell, B. 1997. Ocean survival and exploitation of coho salmon (*Oncorhynchus kisutch*) stocks from the east coast of Vancouver island, British Columbia. Can. J. Fish. Aquat. Sci. 54:1433-1449.

Markle, D.F. 1992. Evidence of bull trout x brook trout hybrids in Oregon. Proceedings of the Gearhart Mountain bull Trout Workshop Oregon Chapter of the American Fisheries Society, 1992.

Maynard, D.J., Flagg, T.A., and Mahnken, C.V.W. 1995. A review of semi-natural culture strategies for enhancing the post-release survival of anadromous salmonids. *In* Uses and effects of cultured fishes in aquatic ecosystems. *Edited* by H.L. Schramm, Jr. and R.G. Piper. American Fisheries Society, Bethesda, Maryland.

Maynard, D. J., Flagg, T.A., Mahnken, C.V.W., and Schroder, S.L. 1996a. Natural rearing technologies for increasing post-release survival of hatchery –reared salmon. Bull. Natl. Res. Inst. Aquacult. Suppl. 2:71-77.

Maynard, D.J., McDowell, G.C., Tezak, E.P., and Flagg, T.A. 1996. Effect of diets supplemented with live food on the foraging behavior of cultured fall Chinook salmon. Prog. Fish-Culturist 58:187-191.

Olmsted, W.R., and McGregor, I.A. 1997. Review of Fraser River steelhead trout (Oncorhynchus mykiss). Prepared for Fraser River Action Plan, Ministry of Environment, Lands and Parks and Department of Fisheries and Oceans.

McMichael, G.A., Sharpe, C.S., and Pearsons, T.N. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring Chinook salmon. Trans. Am. Fish. Soc. 126:230-239.

McPhail, J.D., and Baxter, J.S. 1996. A review of bull trout (*Salvelinus confluentus*) life-history and habitat use in relation to compensation and improvement opportunities. Fisheries Management Report No. 104. Ministry of Environment, Lands and Parks.

Miller, L.M., and Kapuscinski, A.R. Genetic hatchery guidelines for hatchery supplementation programs. *In* Population genetics: principles and practices for fisheries scientists. *Edited by* E. Hallerman. American Fisheries Society, Bethesda, MD. In press.

Nelson, T.C., Alexander, R.F., English, K.K., and Ptolemy, R.A.. 1998. Compilation of stock assessment information for Bella Coola River Steelhead. Report EA1101. LGL Limited, Sidney, B.C.

Nickelson, T.E., Solazzi, M.F., and Johnson, S.L. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43:2443-2449.

Phelps, S.R., Baker, B.M., Hulett, P.L., and Leider, S.A.. 1994. Genetic analysis of Washington steelhead: initial electrophoretic analysis of wild and hatchery steelhead and rainbow trout. Report #94-9. Fisheries Management Program, Washington Department of Fish and Wildlife.

Philippart, J.C. 1995. Is captive breeding an effective solution for the preservation of endemic species? Biol. Cons. 72:281-295.

Rimmer, D.W. 1991. Decline of early winter run wild steelhead in the Stamp/Somass river system. Issue Paper. Ministry of Environment.

Ryman, N., and Laikre, L. 1991. Effects of supportive breeding on the genetically effective population size. Cons. Biol. 5:325-329.

Schiewe, M.H., Flagg, T.A., Berejikian, and B.A. 1997. The use of captive broodstocks for gene conservation of salmon in the western United States. Bull. Natl. Res. Inst. Aquacult. Suppl. 3:29-34.

Slaney, T.L., Hyatt, K.D., Northcote, T.G., and Fielden, R.J. 1996. Status of anadromous salmon and trout in British Columbia and Yukon. Fisheries 21:20-35.

Taylor, E.B. 1991. A review of local adaptation in Salmonidae, with particular reference to Pacific and Atlantic salmon. Aquaculture 98:185-207.

Viola, A.E., and Schuck, M.L. 1995. A method to reduce the abundance of residual hatchery steelhead in rivers. North Am. J. Fish Mngt. 15:488-493.

Walters, C.J., and Cahoon, P. 1985. Evidence of decreasing spatial diversity in British Columbia salmon stocks. Can. J. Fish. Aquat. Sci. 42:1033-1037.

Waples, R. 1999. Dispelling some myths about hatcheries. Fisheries 24:12-21.

Waples, R., and Do, C. 1994. Genetic risk associated with supplementation of Pacific salmonids. I. Captive broodstock programs. Can. J. Fish. Aquat. Sci. 51 (Suppl. 1):310-329.

Ward, B.R., Slaney, P.A., and Tautz, A.F. 1994. Comparison of survival and age at return from the sea of wild and hatchery steelhead smolts of the Keogh River. Can. Spec. Publ. Fish Aquat. Sci. Presented at Internat. Conf. Wild and Enhanced Salmonids, June 17029, 1991, Nanaimo, B.C.

Wightman, J.C., Ward, B.R., Ptolemy, R.A., and Axford, F.N. 1998. A recovery plan for East coast Vancouver Island steelhead trout (*Oncorhynchus mykiss*). Draft Fisheries Project Report. Ministry of Environment, Lands and Parks.

Williams, R.N., Leary, R.F., and Currens, KP. 1997a. Localized genetic effects of a long-term hatchery stocking program on resident rainbow trout in the Metolius River, Oregon. North Am. J. Fish. Mangt. 17:1079-1093.

Williams, T., Currens, K.P., Ward III, N.E., and Reeves, G.H. 1997. Genetic population structure of coastal cutthroat trout. Proceedings from Sea-run cutthroat Trout: Biology, Management and Future Conservation. Orgeon chapter, American fisheries Society.

Wilmot, R.L., and Burger, C.V. 1985. Genetic differences among populations of Alaskan sockeye salmon. Trans. Am. Fish. Soc. 114:236-243.

Yuskavitch, J. 1999. Taking stock of stocking. Trout. Winter:16-27.

Table 1. Summary of all provincial policies associated with fish stocking.

Policy/Procedure Title	effective date	Summary	Recommended changes
Conservation - policy	1993	Conservation of indigenous populations and their habitat is a primary objective of the Ministry of Environment, Lands and Parks.	Requires small additions and changes only to incorporate the idea of "wild" indigenous species, remove use of word "enhancement" and alter the definition of conservation to be made consistent with the Strategic Plan.
Wild Indigenous Fish – policy	1993	First priority of the Fisheries program is the protection, maintenance and enhancement of wild indigenous fish stocks; hatchery reared or exotic species or races will be released only where there is a previous history of stocking or where wild stocks or listed rare species will not be compromised.	None
Lake Stocking of Cultured Fish - procedure	1993	A previously unstocked lake must be inventoried using standard protocols, impacts to native fish species must be analysed, approval must be obtained from Transplant Committee, and priority depends on classification of lake.	Should include a section on the stocking of non-native stocks where the native stock of same species exists; Priority 3 lakes should be reconsidered as even being considered for stocking.
Source of Eggs for Fish Culture - policy	1983	Only wild endemic stocks of salmonids or first generation hatchery fish are planted in lakes where natural selection may occur, and will be used for egg collections except where maintenance of broodstock desirable and cost-effective or wild fish returns are too low.	Too vague – needs some detailed procedures to describe selection of broodstock.
Fish Stocking – policy	1984	The Province will plant hatchery fish only in (1) lakes or reservoirs under 1000 hectares where self-sustaining natural gamefish do not exist or natural	(a)i. of policy regarding lakes or reservoirs and (b) rivers and streams where natural fish populations are under biological carrying capacity

Policy/Procedure Title	effective date	Summary	Recommended changes
		fish populations is less than biological carrying capacity and not capable of sustaining a satisfactory yield of fish; (2) rivers and streams where juvenile fish are at less than biological carrying capacity and current benefit/cost analysis indicates positive benefits; or (3) special circumstances where improved fishery resource is assured.	needs significant changes. This is very poor policy if conservation of wild fish is first priority – this priority needs to be incorporated. Too vague – needs some detailed procedures.
Fish and Aquatic Invertebrate Transplant and Introduction – policy and procedure	1984	Approval of the Federal/Provincial Transplant Committee must be obtained prior to transplant or introduction of fish or aquatic invertebrates	None
Brook Trout Stocking – policy (DRAFT ONLY)	-	The purpose is to minimize the impact of brook trout on native populations of fish, no new lakes will be stocked and only closed systems previously stocked will continue to be stocked	Needs to be formalized

Table 2. Numbers of streams stocked in British Columbia in 1997-2000. Counts sorted by species and region. Treatment to produce non-reproductive stocks includes triploidization (3N) and all-female triploidization (AF3N).

REGION	SPECIES	TREATMENT	1997	1998	1999	2000
1	coastal cutthroat – anadromous	-	9	8	7	3
	steelhead	-	17	10	13*	8*
	TOTAL		**26**	**18**	**20**	**11**
2	coastal cutthroat – anadromous	-	18	18	13	10
	coastal cutthroat	-	1	0	0	0
	rainbow trout	3N	0	1	1	2
		AF3N	-	-	1	2
		-	1	0	0	0
	steelhead	-	11	11	12	9
	TOTAL		**31**	**30**	**27**	**23**
4	kokanee	-	2	3	2	2
	Bull trout	-	1	4	2	2
	Rainbow trout	-	5	3	4	0
	Westslope cutthroat	-	0	1	0	0
	TOTAL		**8**	**11**	**8**	**4**
6	coastal cutthroat – anadromous	-	1	1	0	0
	steelhead	-	1	1	0	0
	TOTAL		**2**	**2**	**0**	**0**
7O	kokanee	-	4	2	1	1
	TOTAL	-	**4**	**2**	**1**	**1**
7P	bull trout	-	1	0	0	0
	kokanee	-	1	1	1	1
	TOTAL		**2**	**1**	**1**	**1**
8	coastal cutthroat	-	1	0	0	0
	rainbow trout	3N	0	3	0	0
		AF3N	0	0	2	2
		-	4	1	0	0
	TOTAL		**5**	**4**	**2**	**2**
GRAND TOTAL			**78**	**68**	**59**	**42**

Table 3. Numbers of lakes stocked in British Columbia in 1997-2000. Counts sorted by species and region. Various treatments to produce non-reproductive stocks include AF = all female, AF3N = all female triploids, MT = masculinized females (only for broodstock) and HERM = hermaphroditic crosses (only for broodstock). Remaining counts represent reproductive strains. Note that some lakes may be stocked more than once with different/same strains of the same species.

REGION	SPECIES	TREATMENT	1997	1998	1999	2000
1	coastal cutthroat - anadromous	-	0	1	62	67
	coastal cutthroat	-	70	67	0	0
	rainbow trout	3N	0	0	37	34
		-	65	62	52	49
	steelhead	-	6	1	4	0
	TOTAL		**141**	**131**	**155**	**150**
2	coastal cutthroat - anadromous	3N	0	1	1	3
		-	1	0	0	0
	coastal cutthroat	3N	1	1	1	1
		-	13	15	13	13
	kokanee	-	1	1	0	1
	rainbow trout	3N	18	26	24	22
		AF3N	0	3	1	23
		MT	0	1	0	3
		-	20	15	25	24
	steelhead	-	1	1	1	0
	TOTAL		**45**	**64**	**66**	**90**
3	brook trout	3N	27	30	0	0
		AF3N	0	0	29	37
		HERM	0	1	0	0
		MT	1	0	3	1
		AF	0	0	1	0
		-	2	0	3	5
	kokanee	-	5	5	7	7
	rainbow trout	3N	16	11	12	17
		AF	12	11	13	9
		AF3N	29	33	39	56
		MT	0	1	0	0
		-	130	104	138	129
	TOTAL		**222**	**196**	**245**	**261**
4	brook trout	3N	15	28	0	0
		AF3N	0	0	2	22
		AF	0	0	1	0
		-	1	1	9	2
	kokanee	3N	0	0	1	0
		-	1	1	1	2
	rainbow	3N	6	8	9	16
		AF	6	6	0	0
		AF3N	1	2	7	1
		-	90	88	74	107
	Westslope cutthroat		1	29	3	23
	TOTAL		**121**	**163**	**107**	**173**
5	brook trout	3N	6	8	0	0
		AF3N	0	0	7	7

REGION	SPECIES	TREATMENT	1997	1998	1999	2000
		-	1	0	9	0
	kokanee	3N	0	0	1	0
		-	9	11	9	12
	rainbow trout	AF	1	2	2	1
		3N	0	0	0	4
		AF3N	0	2	1	28
		-	70	72	80	76
	TOTAL		**87**	**95**	**109**	**121**
6	coastal cutthroat	-	6	4	6	4
	brook trout	3N	0	5	0	2
		AF3N	0	0	4	4
		-	4	0	5	0
	rainbow trout	AF3N	0	0	5	4
		-	9	13	13	15
	TOTAL		**19**	**22**	**33**	**29**
7O	brook trout	3N	0	13	0	0
		AF3N	0	0	18	10
		-	19	0	0	0
	rainbow trout	AF	12	13	18	12
		AF3N	0	2	0	2
		-	43	45	40	32
	TOTAL		**74**	**73**	**76**	**54**
7P	brook trout	3N	0	3	0	0
		AF3N	0	0	3	3
		-	4	0	0	0
	rainbow trout	3N	10	5	2	0
		AF3N	0	4	6	14
		AF	0	0	3	0
		-	10	9	1	1
	TOTAL		**24**	**21**	**15**	**18**
8	brook trout	3N	18	27	0	0
		AF3N	0	0	28	30
		-	0	0	0	1
	rainbow trout	3N	7	5	5	2
		AF	0	2	5	0
		AF3N	105	103	103	107
		-	63	65	71	93
	TOTAL		**193**	**202**	**212**	**233**
GRAND TOTAL			**926**	**967**	**1018**	**1129**

Table 4. Use of non-native stocks in British Columbia streams in 1997-2000 including ACT (anadromous cutthroat trout), KOK (kokanee), RB (rainbow trout), BT (bull trout) and WCT (Westslope cutthroat trout). Stocked that year indicated by y (yes) or n (no).

Region	Species	Origin of stock	Location stocked	1997	1998	1999	2000
1	ACT	Fulford	Colquitz Cr.	y	y	y	y
			Craigflower Cr.	y	n	n	n
		urban brood	Colquitz Cr.	y	n	n	n
		Qualicum	Englishman R.	y	y	n	n
2	ACT	Fraser	Alouette R.	y	y	y	y
			Beecher Cr.	n	y	n	n
			Brunette R.	y	n	y	y
			Byrne Cr.	n	y	n	n
			Chehalis R.	y	y	y	y
			Coquitlam R.	y	n	n	n
			De Boville Slough	y	n	n	n
			Eagle Cr.	n	y	n	n
			Elk Cr.	y	n	n	n
			Frogger Cr.	n	y	n	n
			Harrison R.	y	y	y	y
			Hope Slough	n	y	n	y
			Kanaka Cr.	y	y	y	y
			Maria Slough	y	y	n	n
			Marshall Cr.	y	y	n	n
			Nelson Cr.	n	y	n	n
			Nicomekl Slough	y	y	n	n
			Squawkum Cr.	y	n	n	n
			Stave R.	n	y	y	y
			Stoney Cr.	n	y	y	n
			Sumas R.	y	y	n	n
			Weaver Cr.	y	y	y	y
	RB	Fraser Valley	Coquitlam R.	y	y – 3N	y-3N	y-AF3N
			Similkameen R.	n	n	y-AF3N	y-AF3N
4	WCT	Connor	Joseph Cr.	n	y	n	n
	KOK	Meadow	Lamb Cr.	n	y	n	n
			Bannock Cr.	y	n	n	n
			Springer Cr.	n	y	y	y
			Hill Cr.	y	y	y	y
		Columbia	Illecillewaet R.	n	y	n	n
	BT	Caribou	Burton (Trout) Cr.	n	n	y	n
	RB	Pennask	Slocan Pool	y	n	n	n
		Gerrard	Kikomun Cr.	y	y	n	n

Region	Species	Origin of stock	Location stocked	1997	1998	1999	2000
			Norbury Cr.	y	n	y	n
		Blackwater (Genier)	Slocan Pool	n	y	n	n
7O	KOK	Meadow	Davis R.	y	y	n	n
			Mugaha Cr.	y	y	y	y
			Carbon Cr.	y	y	n	n
			Manson R.	y	n	n	n
			Nation R.	y	n	n	n
	KOK		Cust Cr.	n	n	y	y
8	RB	Fraser Valley	Kettle R.	y	y – 3N	y-AF3N	y-AF3N
			Similkamen R.	y	y – 3N	n	n
			West Kettle R.	y	y – 3N	y-3N	y-AF3N